Appendix C

ROCK BLASTING IN WILMINGTON HARBOR, NC

(adapted from information from Wilmington District, U. S. Army Corps of Engineers, Wilmington, NC. November 1999)

Three environmental impact statements (EIS) have been prepared recently for Improvements in Wilmington Harbor, NC. The first was the Final Supplement to the Final EIS Wilmington Harbor-Northeast Cape Fear River (USACE 1990). This project involved widening the Fourth East Jetty Channel to the West 100 feet and deepening the ship channel to 38 feet from the Cape Fear Memorial (CFM) Bridge to 750 feet above the Hilton Railroad Bridge (figure 1). The second was the Final Supplement I to the Final EIS Wilmington Harbor Channel Widening (USACE 1996a). This project involved the widening of five turns and bends by 75 to 200 feet, and widening by 200 feet the navigation channel in the lower harbor over a 6.2 mile distance to provide a passing lane. The third was the Final EIS Cape Fear-Northeast Cape Fear Rivers Comprehensive Study (USACE 1996b). The project primarily involved deepening the harbor by 4 feet from the Memorial Bridge downstream with some deepening upstream of the Hilton Railroad Bridge. All three of these projects were combined by Congress in 1996 and subsequently called the Wilmington Harbor 96 Act. Since the integration of the projects, several new issues have emerged. These are discussed below.

Blast Design

To accomplish the 96 Act, rock will need to be blasted and removed from the harbor. Test Blasting was conducted to determine the probable blasting designs in the harbor and to test the effectiveness of air curtains in reducing the impacts of blasting. This test blasting was performed from late November 1998 to early January 1999 in an area of the Upper Big Island Channel to be widened. The production blasts during the test blasting consisted of 32-33 holes (3 rows of 10 to 11 holes with each hole and row 10 feet apart), about 52 to 62 pounds (24 to 28 kg) of explosives per hole, stemming each hole (angular rock in the top of the hole), and an approximate 25 msec delay after each hole. Based on the adequate fracturing of rock during the test blasting, for planning purposes only, a similar arrangement and spacing may be used during future blasting contracts except that probably 40 to 50 holes will be used per blast. The number of holes per blast, hole spacing, number of blasts, number of blasts per day, and weight of charge may vary depending on the firm that is awarded the blasting contract. For example depending on the number of drill barges mobilized, 1 to 6 blasts could occur per day. The more blasts per day, the sooner the project would be finished and blast impacts would end. The blasting work will be divided under several contracts with blasting under the first contract scheduled to begin in the Upper and Lower Big Island Channel Areas in the summer of 2000.

USACE 1996 a&b indicated that a typical production blast would involve 80 holes (8 rows of 10 holes each with each row and hole 8 feet apart) with each hole containing 98.5 pounds (45 kg) of explosives. For the combined Wilmington Harbor 96 Act, original estimates were that about 142 of acres of rock surface would require blasting with about 927 blasts based on the 80 hole blast design (Table 1).

It would appear if the number of holes per blast is cut in about half (from 80 in the EIS's to 40 to 50), then the number of blast would be about doubled. This is not the case for two reasons. First, for the original 80 hole pattern, the rows and holes were 8 feet apart versus 10 feet apart for the 40-50 hole pattern. Thus more rock surface area per hole will be affected for the latter pattern. Second, since the Final EIS, there have been more detailed field investigations of the rock locations in the harbor downstream of the Memorial Bridge. These investigations generally indicate less area and volume of rock present compared to original estimates (Table 1). Therefore, the total number of blasts has decreased by about 22 percent (927 to 725 blasts) and the blast area has decreased by 47 percent (142.0 to 74.8 acres, Table 1).

EIS Blast Impact Model versus Test Blast Survival:

USACE 1996 a&b indicated that without an air curtain, the impact area for LD1 (1% or more of the fish would die) for a 0.125 pound fish (2 ounces or about 56 grams) would be 34.5 acres. This equates to a radius of 656 feet from the edge of the blast. The 0.125 pound fish are the smallest fish that could be modeled, and are discussed here because smaller fish are more susceptible than large fish to blast effects. The model in the EIS assumed 25 msec blast delays between each hole and stemming of each hole.

To determine the accuracy of the model predictions during test blasting, generally 50 fish of several species were placed in cages (2 feet diameter by 3 feet long plastic cylinders) 3 feet from the bottom (worst case survival scenario for blast pressure as confirmed by test blast pressure results) at 35, 70, 140, 280 and 560 feet up and downstream of the blast. The air curtain when tested, was 50 feet from the blast. Also, generally 200 fish of each species were held at a control location about ½ mile from the blast location (Moser 1999, USACE 1998). The caged fish consisted of hatchery reared striped bass and shortnose sturgeon (NMFS 1998a) with mean weights of 40 and 55 grams, respectively. Sturgeon cages were enclosed in a 0.6 inch nylon mesh sock to prevent any sturgeon from escaping if the cage was damaged. This was necessary for preservation of the genetic integrity of the resident fish population since the hatchery reared shortnose sturgeon were not the same subspecies as the shortnose sturgeon in the Cape Fear River.

Locally captured fish were also used and consisted of white mullet and killifish that averaged less than 5 grams. All species were placed in separate cages except in cases where collected mullet and killifish had to be combined to comprise a total of 50 fish. All these species were used because they were small and had air bladders, both factors making them more susceptible to blast impacts (O'Keeffe 1984 a&b, Keevin and Hempen 1997, Young 1991), and they were readily available. Aquatic organisms without an air bladder (e.g. shrimp, crabs and clams) are highly resistant to blast impacts (O'Keeffe 1984 a&b, Kevin and Hempen 1997). As indicated above, stemming and an approximate 25 msec delay were used, but 52-62 pounds of explosives were used per hole (versus 98.5 pounds used in the EIS model).

The caged fished were visually inspected for survival just after the blast and after a 24 hour holding period. The survival pattern just after the blast and after the 24 hour holding period were similar. Survival at the monitoring locations 140 feet and beyond just after the blast (with or without air curtain) was not significantly different (figures 2, 3 and 4). The area inside the 140 foot location is about 2.1 acres. Therefore, the EIS model overestimated the impact area by about 94 percent (34.5-2.1/34.5). This percentage and associated area would change little if the number of holes per blast fluctuates because using a delay for each hole creates a series of small blasts versus one large blast. For example, the delay after each hole is approximately 25 msec, while the blast pressure at each hole lasts less than 5 msec.

The reason for the big reduction in blast effect area is probably due to an underestimate in the EIS model of the reduction of blast effects by confining the explosive in rock. Based on investigations by the Corps of Engineers, Waterways Experiment Station (WES), the effect of a blast in rock is 0.014 of a blast in open water. In other words a 52 to 62 pound blast in rock is equivalent to a 0.73 to .87 pound blast in open water (USACE 1999a).

A possible factor for this large reduction is that blasting with a delay after each hole may create its own internal shock absorber. When a blast detonates in water, which is not compressible, the pressure wave travels through water without the pressure being diminished except via distance traveled. However with delays, the first blast creates a mass of gas, which is compressible. Before this gas escapes from the water, the second blast is detonated 25 msec later adjacent to the first blast. The pressure wave generated by the second blast can now be partially spent in compression of the gas present. This process is repeated through each delay. Thus, not only do delays reduce the blast to a series of smaller blasts, but each blast provides a shock absorber for each successive blast.

The average peak pressure and peak impulse pressure at 140 feet without the air curtain (assumed worst case) were 75.6 psi and 18.4 psi-msec, respectively. Peak pressure and peak impulse are common pressure measurements indicated in the literature, but peak impulse is generally considered a better indicator of blast impacts than peak pressure (Munday et. al. 1986, Keevin and Hempen 1997). These values are approximately the same indicated in the literature for threshold of impacts for small fish (Munday et. al 1986, Yelverton et. al 1975).

Air Curtain versus No Air Curtain:

In order to reduce the impacts predicted by the EIS's model, the use of air curtains or a physical barrier was proposed in the EISs. The effectiveness of the air curtain was tested during the test blast project. Three blasts were performed with and four blasts without the air curtain with caged fish in place. Blast pressure readings were taken at the same monitoring locations indicated above for the fish cages (35, 70, 140, 280 and 560 feet upstream and downstream from the blast), with pressure measures taken 3 feet from the surface, mid-depth (about 15 feet) and 3 feet from the bottom (about 30 feet). The air curtain was located 50 feet from the blast (i.e. between the 35 and 70 foot monitoring locations).

Unfortunately, much of the pressure monitoring equipment did not perform properly at the 35 and 70 foot locations. Therefore, an accurate calculation of the pressure reduction potential across the air curtain could not be obtained. Based on the limited data available, the bubble curtain did not appear to reduce peak water shock pressure or peak impulse. The reason the air curtain was not effective was probably because the strong river current distorted or deflected the configuration of the air curtain.

When the average survival rates of the caged fish at the 70 feet location Oust outside the air curtain) with and without the air curtain were compared just after the blast there appeared to be about a 16 percent reduction in apparent survival (loss of equilibrium) with no air curtain for striped bass, mullet and killifish, and 9 percent reduction for shortnose sturgeon (figures 2, 3, and 4). However, the apparent reduction is probably not related to operation of the air curtain (USACE 1999a). The average peak water shock and peak impulse (900 psi and 178 psi-msec, respectively) were higher at the 35 foot location for the non air curtain blasts versus the air curtain blasts (216 psi and 135 psi-msec). This is evident in the lower survival at the 35 foot locations for the non air curtain blasts (figures 2, 3, and 4). These higher pressures at the 35 foot location for non air curtain blasts are probably just due to chance because of the small sample size (3 caged experiments with air curtain and 4 without). However, it is possible that when the air curtain was operating in the strong river currents highly aerated water could have passed over the blast and reduced the pressure before it reached the 35 foot monitoring location.

Regardless of why the pressures are different, there was no difference in survival or impulse pressure at or beyond 140 feet with or without the air curtain in operation. In addition as stated above, for the air curtain tests where the pressure monitoring results are adequate, the air curtain was not effective in reducing peak water shock or impulse pressure (USACE 1999a).

Following the 24 hour holding period, some of the apparent modalities recovered (regained equilibrium). However, these fish and the others that apparently survived unaffected could have died later because of internal injuries that were not fatal within the observation period. Therefore, the condition of the fish and the potential for their future survival was estimated based upon necropsies that were performed on 61 striped bass and 70 shortnose sturgeon surviving after the post-blast 24-hour holding period (Moser 1999). Most of the necropsies were performed on fish from the 35-foot distance (inside the air curtain). Of those that survived at the

35-foot distance, 34 and 88 percent of the striped bass and shortnose sturgeon, respectively, would probably have survived even with internal injures. Survival would be expected to be less for striped bass than for sturgeon since the striped bass were smaller and more laterally compressed making them more susceptible to blast injuries (Department of the Navy 1998). Another possibility is that sturgeon have a free connection from the air bladder to the esophagus perhaps allowing gas to be expelled rapidly during a blast (Moser 1999). Striped bass do not have this connection. However, since blast pressure changes occur so rapidly, there is disagreement in the literature on the benefit of a bladder/esophagus connection (Yelverton et. al. 1975, Keevin and Hempen 1997). Long-term survival even with ruptured air bladders has been documented (Yelverton et. al. 1975, Munday et. al. 1986), and sturgeon exposed to this test blasting that were later placed in holding tanks exhibited no greater long-term mortality (two months) than sturgeon not exposed to blasting (Moser 1999).

Necropsies were performed on 10 shortnose sturgeon at 70 feet without the air curtain in use. All of these fish would probably have survived the blast (Moser 1999). In hindsight, we should have requested more necropsies on all species at the 70 foot distance and beyond. However, assuming all the fish survived as well at the 140 foot distance as the shortnose sturgeon did at the 70 foot location, then the 24-hour holding period would be adequate to determine survival at 140 feet and beyond.

Due to various problems, the impacts of blast pressure on larvae were not determined during the test blasting. As with other size fish, peak impulse should be the best measure for impacts on larvae. The only literature available on impacts of blasting on larvae measures pressure in peak impulse. The LDI for larval fish with air bladders is around I psi-msec (Yelverton et. al. 1975). Such pressures occurred at the edge of the monitored area (560 feet from the blast) with or without the air curtain. However, the blasts are to be restricted to the NC Division of Marine Fisheries dredging window (1 August through 31 January) when larval fish abundance and recruitment are the lowest (CP&L 1980, 1985, and 1994). Also, peak impulse values are similar with or without the air curtain from 140 feet on out. Since these values are similar, air curtains would not be expected to provide a benefit for larvae.

We originally requested approval to blast from 1 August through 31 January, the entire NC Division of Marine Fisheries Dredging window. However due to concerns of potential impacts of blasting on anadromous fish, primarily shortnose sturgeon, January was eliminated. The data indicate that the blast impact area is much smaller than anticipated, and shoftnose sturgeon appear resistant to blasting effects. Therefore, we are again requesting concurrence that blasting may be conducted in January.

Prior to the test blasting, the use of air curtains was estimated to be about $20 million for the project. During the test blasting, the air curtain was difficult to use because of the strong currents, deep water, and frequent repairs required. Because of these difficulties encountered, blasting is expected to take longer and cost more than originally anticipated. Due to the higher costs and minimal, if any, documented benefits of the air curtain during test blasting, we propose elimination of its use in the Wilmington Harbor blasting contract. Stemming, delays between holes, and the environmental monitoring discussed below would still be implemented.

Potential use of a physical barrier as indicated in the Final EIS was not tested during the test blast, but would not have been practical due to the strong currents in the river.

Marine Mammals and Sea Turtles:

Bottlenose dolphin are protected under the Marine Mammal Protection Act of 1972, as amended, and manatees and sea turtles are protected under the Endangered Species Act of 1973, as amended. All these animals have been observed in the Cape Fear River. Dolphin and manatees have been observed at and upstream of Wilmington (located about mile 25 to 27) whereas sea turtles have been observed only as far upstream as mile 15 (NMFS 1996). Blasting will occur from approximately river mile 18 upstream. USACE 1996b indicated that pre and post blast surveys would be made for marine mammals (including bottlenose dolphins and manatees) and sea turtles. Coordination after the Final EIS related to the test blasting program, resulted in a recommended survey area 1,000 feet upstream and downstream of the blast area. This area was surveyed for all test blasts and no marine mammals or sea turtles were observed.

Marine mammals and sea turtles can be physically damaged by blasts pressures, and affected by noise levels. Some injury can occur to bottlenose dolphins at or above 1. 1 7 in-lb/in2 (energy flux density)(Department of the Navy 1998) or above 5 psi-msec for impulse pressure (Yelverton 1973). The maximum test blast value recorded for energy flux density at 560 feet was 0. 1 95 in-lb/in2, and for impulse was 5.86 psi-msec. Noise levels from 1 1 5 to 180 decibels (dB) or 12 psi can cause a change in movement or behavior (harassment) for marine mammals, sometimes referred to as a Temporary Threshold Shift (TTS) (Richardson et. al. 1995, Ridgeway et. al. 1997, Department of the Navy 1998). We did not monitor noise levels during the test blast, but peak pressure was measured and can be converted to dB (Sayigh 1999, Military Analysis Network 1999). The maximum peak pressure of 15 psi measured at 560 feet from the blast would equate to 67dB.

The pressure and dB values recorded during the test blasting at 560 feet indicated above are near or below the indicated thresholds. Therefore, a 1,000-foot radius monitoring zone should be adequate to survey for marine mammals. This monitoring should also be adequate for sea turtles since the threshold of impacts is probably similar to that bottlenose dolphins (Department of the Navy 1998). Several literature models (e.g. Young 1991) are available to estimate a blast safety zone for marine mammals and sea turtles. However, none of these models are based on data from rock blasting in Wilmington Harbor. The proposed 1,000-foot radius should be more than adequate since it is based on actual data from the Wilmington Harbor Project.

As indicated previously, the farthest downstream blast area for the Wilmington Harbor 96 Act is approximately 18 miles upstream of the ocean; therefore, whales should not be affected.

Mitigation:

Mitigation for the loss of fisheries habitat was discussed in detail in the ElSs related to the Wilmington Harbor 96 Act (USACE 1990, 1994a&b, 1996a&b) and in the Final Mitigation Plan for the 96 Act (USACE 1999b). This included consideration of loss of bottom habitat where blasting would occur. No mitigation was proposed for the act of blasting because blasting in and of itself will not result in a permanent additional loss of habitat. Blasting will impact organisms in the water column near each blast during the short time each blast occurs (1.25.seconds = 25 msec between holes x 50 holes per blast). Impacts of each blast were minimized to the extent feasible by using air curtains, a delay after each hole, stemming, and blasting only during the NC Division of Marine Fisheries dredging window (I August through 31 January). The only difference proposed is the elimination of air curtains because they were not effective in reducing blasting impacts, and the impact area is 94 percent less than predicted in the ElSs (USACE 1996a&b).

Environmental Commitment and Monitoring:

All the environmental commitments made in USACE 1996a&b remain in force except as modified below.

As indicated above, pressure measurements were taken during the test blasting at several locations. With or without the air curtain, there were no impacts to caged fish beyond the 140-foot locations. The peak pressure values recorded at this location without the air curtain averaged about 75 psi with a maximum of 131 psi. Therefore an average of 70 psi and a maximum of 120 psi should be reasonable thresholds at 140 feet that should not be exceeded during production blasting in order to protect marine life. These thresholds would be used for each series of 5 blasts. Peak pressure would be recorded versus peak impulse, because peak pressure is easier to measure.

No caged fish will be monitored, and except for the threshold pressure readings indicated above at 140 feet for each blast, no other pressure readings are proposed during production blasting. However the following actions conducted during the test blasting (with any modifications indicated) would be continued during production blasting.

1. Blasting was restricted to the months of August through December, inclusive. January was originally eliminated potential over impact concerns to shoftnose sturgeon.

Following coordination of preliminary results of minimal impacts to sturgeon, blasting into early January was allowed (NMFS 1998b). Based on the final results indicated in this EA that shodnose sturgeon don't appear to be greatly affected by blasting with or without air curtains, and extensive gill netting indicated below should preclude them from entering the blast site, blasting in January is proposed again.

2. An approximate 25 msec delay per hole and stemming each hole will still be required.
3. Before each blast, four (4) sinking gilinets (5.5 inch mesh, 100 meters long) were set to surround the blast area as near as feasible. These nets were in place for at least 3 hours and none of the nets were removed any sooner than 3 hours before the blast. This required overnight sets. The nets were manned continuously to prevent obstructing the channel to ship traffic. Each sturgeon removed (shortnose or Atlantic) was tagged with a t-bar tag, and the sturgeon released in the Brunswick River within 100 meters of the bridge.

   The same netting procedure is proposed except the nets will not be removed any sooner than I hour before the blast," Only one sturgeon (Atlantic) was captured during test blasting and it was tagged and released in the Brunswick River. This same sturgeon was recaptured later in the test blast area.

4. Within 10 minutes of each blast, a large mesh (1-2 inch mesh) channel net was set immediately downstream of the blast area to capture sturgeon that were injured or killed during blasting. To test the efficacy of the channel net, for each blast involving caged fish, a group of 30 dead sturgeon were marked uniquely and the sturgeon released on the river bottom upcurrent of the net.

   None of the released dead sturgeon were captured by the channel net. This was probably because the set had to be over 600 feet from the blast due to all the monitoring equipment present. The channel net should be set within about 300 feet during production blasting. Setting it any closer would violate safety

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Table 1. Wilmington Harbor, 1996 Act. Rock surface area, volume, and number of blasts required for project components (assumes 42 foot channel + I foot of required overdepth in rock + 1 foot of allowable overdepth 44 feet deep).

	Area of Rock Blasting (acres)		Volume (cu. yards x 1000)		Number of Blasts	
Project	Prior	Now	Prior	Now	Prior[1]	Now[2]
Wilmington Harbor - Northeast Cape Fear River **(NECF)**	32.5	32.5	406	406	210	315
Wilmington Harbor Channel Widening **(CW)**	20.2		70		122	
Cape Fear-Northeast Cape Fear Rivers Comprehensive (USACOE 1996b) (**CFC**)	89.3		601		595	
Prior Subtotal (**CW +CFC**)	109.5		671		717	
New Subtotal (**CW +CFC**)		42.3		275		410
Total: Wilmington Harbor, 96 Act (**NECF + CW + CFC**)	142.0	74.8	1,077	681	927	725
Percent Reduction		47%		37%		22%

(1) Based on 80 hole pattern with 8 foot spacing between holes and rows.

(2) Based on 45 hole pattern with IO foot spacing between holes and rows.